Critical Viscosity of Xenon-2 (STS-107)

Whipped cream stays in place even when turned upside down. Yet it readily flows through the nozzle of a spray can to reach the dessert plate. This demonstrates the poorly understood “shear thinning” phenomenon that is important to many industrial and physical processes. Modern society uses paints, film emulsions, and other complex solutions that are highly viscous under normal conditions but become thin and flow easily under shear forces.

Viscosity—the “thickness” of fluids—is determined by complex interactions between molecules. Except for low density helium, fluid viscosity cannot be predicted accurately by current theory. However, progress is being made with experiments using simple fluids near their critical points, at which a fluid is balanced between the states of liquid and gas. This balance causes the fluid to fluctuate spontaneously between liquid and gas at a microscopic scale. The fluctuations make the xenon somewhat like a soft drink with carbonation bubbling in and out. Tests with critical fluids can provide key data, but are limited on Earth because these fluids are highly compressed by gravity.

The Critical Viscosity of Xenon-2 Experiment (CVX-2), scheduled to fly on the STS-107 mission, will measure the viscous behavior of xenon—a heavy, inert gas used in flash lamps and ion rocket engines—at its critical point. Although it does not easily combine with other chemicals, its viscosity at the critical point can be used as a model for a range of chemicals. CVX-2 employs a tiny metal screen vibrating between two electrodes in a bath of critical xenon. The vibrations and how they dampen are used to measure viscosity.

CVX-1, which flew on the STS-85 mission, revealed that when close to the critical point, xenon is partly elastic: it can “stretch” as well as flow. And CVX-1 showed that xenon’s viscoelastic response was twice as great as predicted by theory. For STS-107, the hardware has been enhanced to determine if critical xenon is a shear-thinning fluid.

An understanding of shear thinning in a simple fluid like xenon will help scientists understand the phenomenon in more complex, industrially important fluids, such as:

- Paints, emulsions, and foams.
- Polymer melts.
- Pharmaceutical, food and cosmetic products.

Resembling a tiny bit of window screen, the oscillator at the heart of CVX-2 will vibrate between two pairs of paddle-like electrodes. The slight bend in the shape of the mesh has no effect on the data.

Affected Fields

Technologies: Processes that use such complex fluids as polymers, processed foods, emulsions, and foams.

Physics: Universal behavior of pure fluids at the liquid-vapor critical point.

The thermostat for CVX-1 sits inside the white cylinder on a support structure inside a pressure canister. The CVX-2 arrangement is identical.

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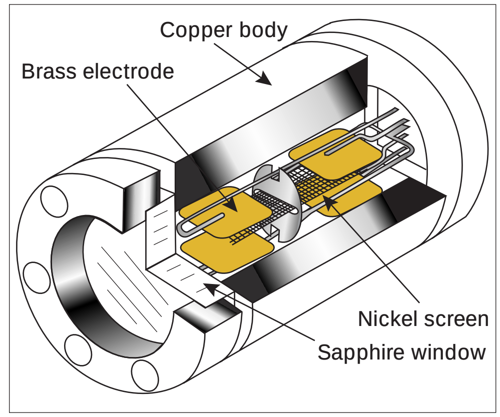
Science

Viscosity experiments on Earth are severely limited by the effects of gravity. Even a fluid layer as thin as a dime (1mm or 0.04 in.) collapses under its own weight, thereby increasing the density at the bottom. Experiments in the microgravity of orbit eliminate density differences and allow extended experiments to achieve the precision that scientists need.

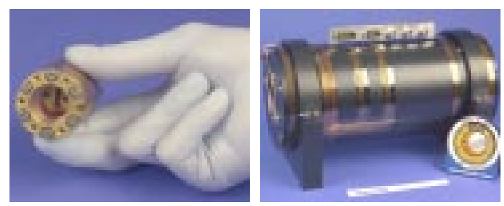
Shear-thinning occurs in complex fluids, such as paints and blood, that become "thin" and flow easily under a shear stress such as stirring or pumping. CVX-2 will be the first experiment to examine the shear-thinning phenomenon in a simple fluid.



The CVX canisters, outlined in yellow, in the Technology, Applications, and Science (TAS-01) payload for STS-85 in 1997. This view shows the top of TAS-01 in the payload transporter before installation in the Shuttle. The FREESTAR payload on STS-107 has a similar configuration

Hardware

The heart of CVX is a viscometer comprising a nickel screen that vibrates between two pairs of brass electrodes in a xenon bath at the critical point. The grid is 7 x 19 mm (0.28 x 0.74 in) and weighs less than 1 mg. An electrode is positioned 4 mm (0.16 in) to each side of the screen. An electrical charge applied by the electrodes will oscillate the screen. The electrodes then measure the screen's displacement and period, like a pendulum swinging in a liquid.



The sample cell (left) at the heart of CVX will sit inside a thermostat (right) providing three layers of insulation. The cell itself (below) comprises a copper body that conducts heat efficiently and smoothes out thermal variations that that would destroy xenon's uniformity.

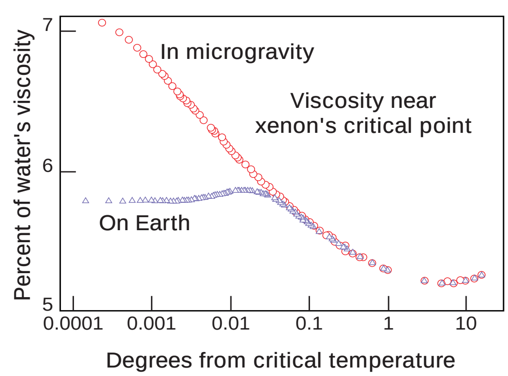
Because the critical condition of xenon requires microdegree control, the sample cell is a copper cylinder, 62 mm long by 38 mm wide (2.45 x 1.5 in) that conducts heat well and adds thermal inertia to ensure slow, even changes in temperature. The cell is enclosed in a three-layer thermostat to improve thermal control.

The complete CVX-2 system is contained in two Hitchhiker canisters mounted on the Multi-Purpose Equipment Support Structure (MPESS) in the Shuttle payload bay as part of the FREESTAR payload. One canister holds the thermostat, batteries, and analog-control electronics. The second canister holds the control electronics, data recorders, and communications system.

CVX-2 Operations

CVX-2 will start functioning after the Space Shuttle crew activates it during orbit. Normal operations are automated, but CVX-2 can be controlled from a payload control center at NASA's Goddard Space Flight Center. The experiment plan involves four "sweeps." That is, the temperature will be gently moved up and down while the screen oscillates and data are continuously recorded.

On CVX-1, the screen oscillated at less than 13 cycles per second (13 Hz) through a distance of less than 0.01 mm, less than the thickness of a hair, to avoid disrupting the density fluctuations in the xenon. On CVX-2, the screen vibrates at up to 25 Hz and amplitudes of 0.3 mm in a deliberate attempt to disrupt the density fluctuations and cause shear thinning. Even so, the total heat dissipated through the xenon is only a few billionths of a watt.



Because xenon near the critical point will collapse under its own weight, experiments on Earth (blue line) are limited as they get closer (toward the left) to the critical point. CVX in the microgravity of space (blue line) moved into unmeasured territory that scientists had not been able to reach.